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Original Article

DEVELOPMENT AND STUDY OF TRIBOLOGICAL PROPERTIES OF BIOCOMPOSITE FOR BRAKE PAD APPLICATION

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ABSTRACT

Pollution is the adverse effect humanity has to suffer due to the technological advancement. Being engineers our objective is to design the machine elements based on sustainable, eco-friendly concepts. Due to wear in brake pad, abrasive particles come to environment. So the material selection of brake pad is an important criterion. In a braking system brake pad comes in contact with the disc and due to heavy friction the kinetic energy of the vehicle reduces and it comes to rest. Generally in this process a lot of wear occurs in brake pad and the abrasive particles comes out of the brake pad. In the brake pad composites asbestos has been used as reinforcement for a very long period of time. Few years before it was found that asbestos particles having carcinogenic effect on the skin. So a lot of research is going on for finding a suitable replacement for asbestos. The objective of this research is to find the suitability of using natural fiber composite material as a replacement for asbestos. Hemp fiber is chosen in the place of asbestos which comes from the stem of the hemp tree. It is a natural fiber having very high young's modulus and cellulose content. Cashew friction dust is chosen to improve frictional properties, graphite powder is used as solid lubricant and epoxy is used as matrix material for the brake pad composite. The composites with varying compositions were being fabricated using compression molding machine using an acrylic die followed by post curing in a furnace. Then few important properties like wear rate, coefficient of friction, density and hardness were evaluated. Pin on Disc investigation is performed on the composites for analyzing the wear rate and frictional behavior of composites. Finally the results were compared with that of the existing literature.

***KEYWORDS:** Eco Friendly Composite, Tribology & Break Pad*

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INTRODUCTION

Braking system is highly essential for all vehicles. It can be broadly classified into two major categories such as drum brakes and disc brakes. A drum brake system has a set of shoes that press outward against a rotating cylinder shaped part called brake drum. A disc brake system has calipers that squeezes a pair of brake pads against a rotating disc in order to create friction that will retard the motion of the disc. Brake pads are important parts of braking system for all types of vehicles that are equipped with disc brake. Brake pads are steel backing plates with friction material bound to the surface facing the brake disc. Brake pads convert the kinetic energy of the vehicle to thermal energy by friction. Two brake pads are contained in the brake caliper with their friction surfaces facing the rotor. Brake pad materials are classified as belonging to one of the four principal categories such as: Non-metallic, semi-metallic, metallic, ceramic materials. Metallic and semi-metallic friction materials show better thermal stability and wear characteristics as compared to the non-asbestos organics but they generate more noise and degrade the disc material faster. Ceramic materials can withstand very high temperature and makes very less noise.

Since the cost is very high they are suitable for high speed vehicles where cost is not an issue. The objective of the research is to develop new brake pad materials for replacing asbestos based brake pads. There are four major categories of brake pads used in the automobile industry such as: non asbestos organics, semi-metallic materials, fully-metallic materials, ceramic materials. There is a possibility of using natural fibers for the development of brake pad composites [3]. There are four major varieties of materials that are being used in brake pad composites such as reinforcement, matrix, frictional modifiers and solid lubricants. The reinforcement provides strength to the composite. Frictional modifiers are used for increasing the coefficient of friction and solid lubricants are used for providing thermal stability. Hemp fiber is chosen as reinforcement for the development of the composite [6]. Tensile strength and young's modulus are very high for hemp fibers compared with other natural fibers. Hemp fibers contain more cellulose content which provides it more thermal stability and it contains a reasonable lignin content which is removable by NAOH treatment for increasing the compatibility with the matrix [2]. Epoxy is chosen as resin for the composite since it is found to be compatible with hemp fiber [5]. Cashew friction dust is derived from cashew nut shell which is ultimately a waste after cashew is being removed from it and it is also a bio material [1]. Graphite powder is used in the composite as a solid lubricant. All the materials are mixed thoroughly and then the mixture is injected inside the mould cavity. The composites were fabricated using compression moulding technique, followed by post curing in an oven [4]. Pin on disc investigation is done to test the wear rate and frictional performance of the composites [7]. The surface microstructure of the composite is observed through video microscope [8]. Rockwell hardness tester is being used for comparing the surface hardness of both the composites.

Fabrication

The first step in the process of fabrication is the material selection. A brake pad composite generally consists of several materials. In this research work brake pad composites are being developed by using four different materials. A natural fiber is chosen as a reinforcement and a cashew friction dust is used as frictional modifier. Graphite powder is used to increase the thermal conductivity and it will act as a solid lubricant in the composite. Epoxy resin is used for binding the reinforcement, frictional modifier and solid lubricant. Table 1 and Table 2 depicts the reason for the usage of hemp fiber as reinforcement.

Table I: Mechanical Properties of Natural Fibers

Fiber	Tensile strength (MPa)	Young's modulus (GPa)
Abaca	400	12
Bagasse	290	17
Bamboo	140–230	11–17
Flax	345–1035	27.6
Hemp	690	70
Jute	393–773	26.5
Kenaf	930	53
Sisal	511–635	9.4–22
Ramie	560	24.5
Oil palm	248	3.2
Pineapple	400–627	1.44
Coir	175	4–6
Curaua	500–1150	11.8

The tensile strength of hemp fiber is 690 Mpa and the young's modulus is 70 Gpa, which is very high as compared to other natural fibers. Cellulose content of hemp fiber is very high as compared to other natural fibers. Cellulose content in any natural fiber is responsible for its strength and thermal stability. Hence, hemp fiber is chosen as

reinforcement in the composite material.

Table II: Chemical Composition of Natural Fibers

Fiber	Cellulose (wt. %)	Hemicellulose (wt. %)	Lignin (wt. %)
Bagasse	55.2	16.8	25.3
Bamboo	26–43	30	21–31
Flax	71	18.6–20.6	2.2
Kenaf	72	20.3	9
Jute	61–71	14–20	12–13
Hemp	68	15	10
Ramie	68.6–76.2	13–16	0.6–0.7
Abaca	56–63	20–25	7–9
Sisal	65	12	9.9
Coir	32–43	0.15–0.25	40–45
Oil palm	65	-	29
Pineapple	81	-	12.7
Curaua	73.6	9.9	7.5
Wheat straw	38–45	15–31	12–20
Rice husk	35–45	19–25	20
Rice straw	41–57	33	8–19

For increasing the compatibility of hemp fiber with epoxy matrix the hemp fiber is being treated with 5% NAOH for 5 hours and then washed in water properly. The treated fiber is sun dried for one day before the usage as reinforcement in the composite.

Figure 1: 5% NAOH Treated Hemp Fibers

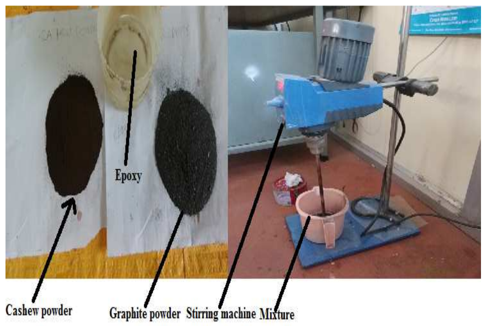

Figure 2: Stirring Machine is Mixing the Powders with Epoxy Resin

All the constituent materials need to be mixed properly, in order to have a homogeneous mixture. The two powders were initially stirred with epoxy resin, according to the composition in an IKA 20 Kw stirring machine. The stirrer has the capacity of rotating at 1500 R. P. M. Initially, one powder is mixed with epoxy resin and it is stirred for 1hour at 300 R. P. M. and then, another powder is mixed and the mixture is stirred for one more hour. The powders were mixed with the epoxy resin using the stirrer and then, the chemically treated hemp short fibers were mixed in the mixture, manually. Hardener is added in the mixture in 1:10 ratio, with the resin. The mould is cleaned properly and then wax is applied in all the holes. Wax layer is useful for taking out the samples from the mould cavity. The mixture is injected inside the 10 mm diameter holes. Then the die is placed inside the compression moulding machine and a hydraulic pressure of 10 bars is applied on it. The Sample is taken out of the compression moulding machine and cured in an oven at 70 degree centigrade for 3 hours. Then the composites were taken out from the mould.

Figure 3: Compression Moulding Machine Used for the Fabrication

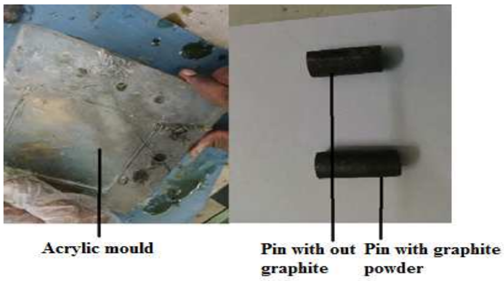

Figure 4: Acrylic Mould and the Fabricated Pins

EXPERIMENTAL RESULTS AND DISCUSSIONS

A pin on disc test apparatus as shown in figure 4.2 is used to investigate the dry sliding wear characteristics and coefficient of friction values for both the composites with cast iron and stainless steel discs. Cast iron and stainless steel disc has been procured and machined according to the Ducom machine specifications, as shown in the figure 4.1. The fabricated composites were surface grinded and then 3 layers of polishing are done with 300, 600 and 1000 grades of sand papers. The composites of 10mm diameter and 25 mm length were tested with both cast iron and stainless steel discs at 4kg load and 3.14m/s sliding velocity for 5000m sliding distance. Two tracks of 80 mm and 60 mm diameter has been used for the tests. The surface microstructure and weight of the pin is measured before and after the testing. The variation of coefficient of friction with respect to time can be observed through Winducom software. The formula used to convert the weight loss into wear rate is:

$$\text{Wear rate}=\frac{\Delta w}{s} \tag{1}$$

Where Δw = weight loss

S= sliding distance in meters

Digital weighing machine having accuracy up to five digits has been used to measure the weight loss. The surface should be perfectly flat for taking the accurate readings. There is a provision of spirit bubble in the digital weighing machine for measuring the surface flatness. There are two knobs in the bottom of the digital weighing machine to adjust the height of the device so that the bubble comes inside the circle. Once the bubble is placed perfectly inside the circle the readings can be taken.

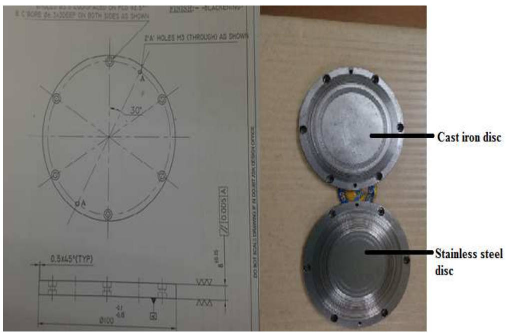

Figure 5: Specification of Disc and the Fabricated Discs

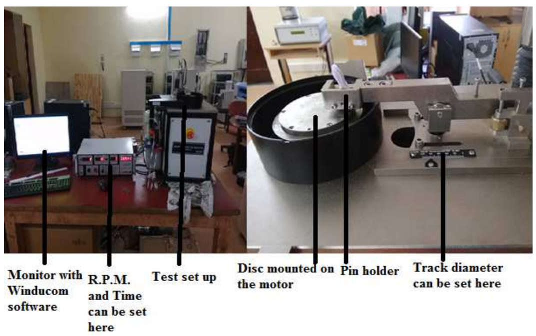

Figure 6: Working of Pin on Disc Machine

Figure 5 shows the mechanical drawing of the disc that is going to be used in the Pin on disc machine as the

counter part of the composites. The disc is having 100 mm outer diameter and 8 mm thickness. The surface of the disc is grinded using ultrafine grinding wheel to achieve a surface finish of 1 to10 micro meters. There are provisions of 6 threaded through holes to attach the disc with the rotor. On the right hand side of the figure 4.1 the fabricated discs with cast iron and stainless steel materials are shown. Unlike stainless steel discs cast iron disc is having many casting defects. The fabricated composites were tested with both the discs. There is visible track surface damage since each track has been used for so many times. The wear and friction monitor as shown in figure 6 is fully guarded for operator safety and can determine the wear and coefficient of friction of metals and polymers. The sliding path is a circle on the disc surface. This machine is designed to apply loads up to 100N and speeds starting from 100 to 1000 rpm.

Table III: Wear Rate and Coefficient of Friction with Stainless Steel Disc

Serial No.	Composition	Wear Rate in (gm./m)*10-6	Coefficient of Friction
1	20% graphite sample1	2.506	0.375
2	20% graphite sample 2	2.024	0.437
3	20% graphite sample 3	1.662	0.413
4	0% graphite sample 1	1	.471
5	0% graphite sample 2	1.064	0.58
6	0% graphite sample 3	0.982	0.517

Table III illustrates the results obtained from the experiments conducted with the composite pins with stainless steel disc at 4kg load, 3.14 m/s sliding velocity, 5000 m sliding distance, 80 mm track diameter, 750 R. P. M. for 26.54 min. Three samples were taken from both the compositions. Each pin tested in above mentioned testing parameters and wear rate and coefficient of friction is measured. Wear rate is the weight loss per meter of sliding distance. Hence weight of the pins were measured using a high precision weighing machine. Three readings of weight is taken for each pin and then average is taken out to avoid error. The wear rate and coefficient of friction value differs for each sample even though they are having same compositions. The variation in wear rate for 20% graphite is more as compared to 0% graphite composites.

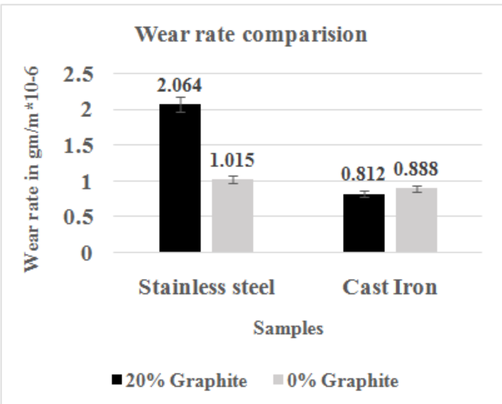

Figure 7: Wear Rate Comparison with Disc Material and Composition of Brake Pad

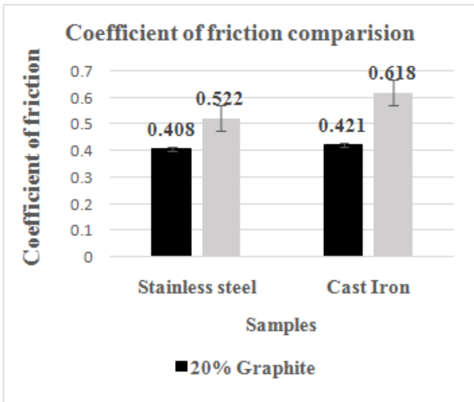

Figure 8: Coefficient of Friction Comparison with Disc Material and Composition of Brake Pad

Wear rate variation with the composition in the composite and with the disc material is shown in the figure 7. All wear rate data are taken in the order of 10^{-6}gm/m. The wear rate values shown in the bar chart are the average of the readings taken for three different samples. The wear rate is observed to be highest for 20% graphite sample when tested with stainless steel disc. The same 20% graphite samples have shown much less wear rate when tested with cast iron disc.

The wear rate is more with stainless steel disc as compared to cast iron disc. The variation in wear rate for stainless steel disc with the composites is more as compared to cast iron disc. Coefficient of friction variation with the composition in the composite and with the disc material is shown in the figure 8. The coefficient of friction of 0% graphite is more as compared to the 20% graphite composite with stainless steel disc. In case of cast iron disc the composites without graphite have shown much higher value of coefficient of friction. The overall coefficient of friction is increasing with the cast iron disc as compared to the stainless steel disc.

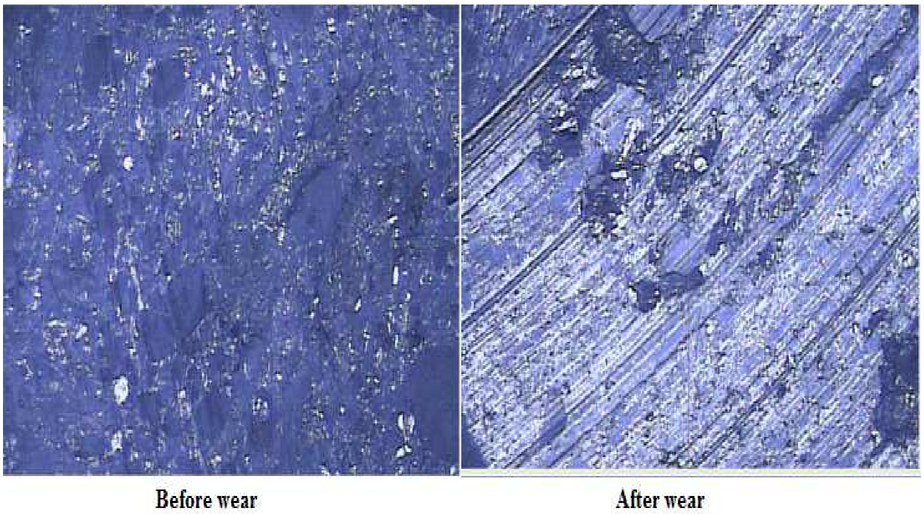

Figure 10: Microstructure of 20% Graphite Sample 1 before and After Wear

Figure 9 and 10 reveals the microstructure of the surface of the composite before and after the wear test is done. In case of 0% graphite before wear there are few surface defects visible and after the wear there is a severe damage in the surface quality of the composite. The coefficient of friction is high for 0% graphite composite but the surface quality is degrading severely. 20% graphite composite is showing less surface damage as compared to 0% graphite composite.

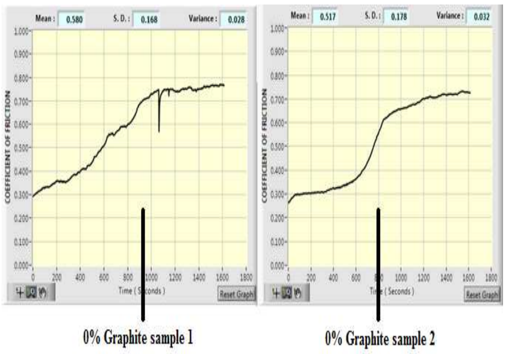

Figure 11: Variation of Coefficient of Friction with Time for 0% Graphite Samples with Stainless Steel Disc

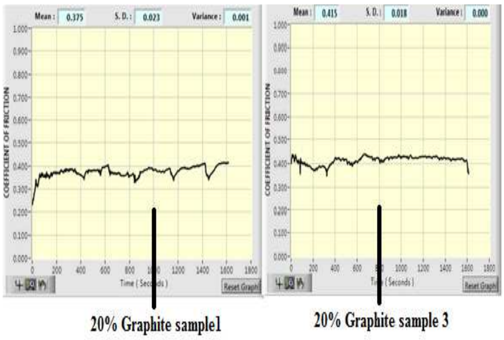

Figure 12: Variation of Coefficient of Friction with Time for 20% Graphite Samples with Stainless Steel Disc

Figure 11 and figure 12 illustrates the variation in coefficient of friction with respect to time in both the composites tested with stainless steel disc. There is a rise in the value of coefficient of friction in case of composites without any graphite content. The one possible explanation can be rise in temperature. The 0% graphite composites might be thermally unstable. The microstructure of the composite reveals a severe damage in the surface quality in 0% graphite composites which might lead to rise in coefficient of friction. The 20% graphite samples have shown much stable coefficient of friction value. There is a little fluctuation in the graph due to vibration and some experimental error.

Table IV: Hardness value in HRM

Sample No	20% Graphite	0% Graphite
Sample 1	48.7, 56, 60.3 = 55	74.4, 79.1, 70.9= 74.8
Sample 2	53.1, 52.5, 48.7= 51.43	77.4, 77.8, 79.6= 78.26
Sample 3	52.7, 56.8, 49.1= 52.86	74.2, 74.1, 69.9= 72.73
Sample 4	44.5, 39, 50.7= 44.73	44.7, 45, 42.7= 44.13
Sample 5	59.3, 50.2, 59.7= 56.4	77.4, 67.2, 60.5= 68.33

Table IV gives a clear indication about the Hardness of the composite. The overall hardness value of 0% graphite is more as compared to 20% graphite. Five samples were taken from each compositions. The surface hardness values were measured in three different places of the surface and the average of those values were taken as shown in table IV. All the hardness values are being measured in HRM scale. The surface hardness of stainless steel disc in higher than cast iron disc.

Table V: Comparison with Existing Literature

Properties	Wear Rate in gm/m.106	Coefficient of Friction
Commercial brake pad (5.02 m/s)	3.8	0.3-0.4
Palm kernel Shell(5.02 m/s)	4.4	44
Baggase(5.02 m/s)	4.2	42
Abaca fiber (5.02 m/s)	4.15	44
Bagasse ash particulate composite (3.14 m/s)	1.57	
Hemp fiber composite with 20% graphite (3.14m/s)	2.064	408
Hemp fiber composite with out graphite (3.14m/s)	1.015	552

The tribology properties of brake pad composites were compared through table V. The results obtained for new composites indicate the potential of the new materials in brake pad application.

CONCLUSIONS

- Bio-composites were fabricated in a compression moulding machine using epoxy, hemp fiber, cashew friction dust and graphite powder. The constituent materials were found to be compatible with each other.
- The fabricated composites were tested with stainless steel and cast iron discs using a pin on disc machine. The wear rate in case of cast iron disc is less as compared to the stainless steel
- disc having similar coefficient of friction value. The surface hardness value of stainless steel is more than cast iron disc. With increase in hardness of disc material the wear rate of pin material increases.
- The wear rate of 20% graphite composites is higher than 0% graphite composite whereas the coefficient of friction is high in case of 0% graphite composites. It can be inferred from both the results that the composites without graphite content gives better performance in tribology aspect.
- Zero percent graphite sample has more surface damage than 20% graphite sample.
- The Rockwell hardness test reveals the surface hardness value of both the composites. The 0% graphite composites have higher value of surface hardness as compared to the composites having 20% of graphite content. Hence with increase in surface hardness of pin material the wear rate decreases.
- Thermal stability of composites increased due to graphite powder addition.
- The wear rate and coefficient of friction data were compared with that of the existing results for commercial vehicles and it is observed that the new composites are having the potential for frictional material in brake pads in tribology aspect.

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